Hubble's Science Legacy: Future Optical-Ultraviolet Astronomy from Space
ASP Conference Series, Vol. 000, 2002
K.R. Sembach, J.C. Blades, R.C. Kennicutt, G.D. Illingworth (eds.)

High Resolution Ultraviolet Quasar Absorption Line Spectroscopy of $z \sim 1$ Galaxy Group

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Abstract. We used ultraviolet spectra from HST/STIS ($R = 30,000$), together with optical spectra from Keck/HIRES ($R = 45,000$), to study the three MgII-selected absorption systems at $z = 0.9254$, 0.9276, and 0.9342 toward the quasar PG $1206+459$. A multi-phase gaseous structure, with low-ionization components produced in small condensations and high-ionization ones in diffuse clouds, is indicated in all three systems. Each system is likely to represent a different galaxy with absorption due to some combination of interstellar medium, coronal gas, halo gas, and high-velocity clouds. Even with the improved sensitivity of HST/COS, we will only be able to obtain high-resolution ultraviolet spectra of the brightest quasars in the sky. A larger telescope with ultraviolet coverage will enable quasar absorption line studies of hundreds of galaxies, including a wide range of galaxy types and environments at low and intermediate redshifts.

1. Introduction

The lightbeams from distant quasars pass through various galaxies and probe physical properties of gaseous structures in the galaxies. Therefore, studying absorption features in the background quasar spectrum is a unique method for tracing the cosmic evolution of the universe. Strong MgII absorbers are almost always associated with luminous galaxies ($> 0.05L^*$). Thus, using this tool we can study the predecessors of the giant spiral and elliptical galaxies that we see in the nearby universe.

Three MgII systems (A, B, and C), at redshifts $z = 0.9254$, 0.9276, and 0.9342, are found along the line of sight toward the quasar PG $1206+459$. In a previous study, Churchill & Charlton (1999) found the three systems to be multi-phase absorbers with MgII clouds embedded in extended, high-ionization gas that gives rise to CIV, NV, and OVI. Their analysis was based upon the combination of low-resolution data from HST/FOS and high-resolution data from Keck/HIRES. However, many important issues remained unresolved, such as (1) whether CIV, NV and OVI arise in the same layer of gas and whether their profiles are smooth or have sub-structure; (2) whether the high-ionization phase "envelops" the low-ionization phase or whether it is offset in velocity; (3) whether the majority of SiIV in the $z = 0.9276$ system arises in a single MgII cloud that is similar to a Milky Way high-velocity cloud.

In May 2001, we obtained a stunning high-resolution ($R = 30,000$) HST/STIS spectrum, covering Lya and high-ionization transitions SiIV, CIV, and NV, for the three systems. Through photoionization modeling of the various chemical transitions in this spectrum and in the earlier Keck/HIRES spectrum, the metallicities, abundance patterns, and ionization states of absorbing gas clouds have been constrained (for details on the modeling technique, see Ding et al. 2002). The results are presented in the following sections along with the physical interpretations of individual phases of gas.

2. System A at $z = 0.9254$

Six clouds, spread over $v \sim 200$ km/s in velocity space, are needed to fit the MgII absorption. Ionization parameters are constrained to be $-2.8 \lesssim \log U \lesssim -2.5$ and the metallicity is required to be super-solar, if a solar abundance pattern is assumed. These clouds, all having $\log N(\mathrm{HI}) < 16$, contribute negligibly to the partial Lyman limit break. The dotted lines in Figure 1 represent the contribution from the MgII phase, for our best model.

A diffuse phase is required to fit the residuals in CIV, NV, and OVI, unaccounted for by the MgII phase. Collisional ionization is ruled out as a mechanism to produce the NV absorption, due to the narrow features in the high-resolution spectrum. The ionization parameters of the seven high-ionization clouds are constrained to be $-1.5 \lesssim \log U \lesssim -0.6$. A super-solar metallicity is also required in this phase, unless N is enhanced. In Figure 1, solid lines represent the contribution from this diffuse phase.

Neither the low-ionization phase or the diffuse phase could fully account for the residuals to the red of the CIV profiles. An additional component, with $b(\mathrm{C}) \sim 6$ km/s, seems to be necessary. This component could be photoionized or collisionally ionized. A near-solar metallicity is required in either case. The photoionized component, with an intermediate ionization parameter $\log U \simeq -2$, is represented by the dashed-dotted curves in Figure 1.

The large kinematic spread of the MgII, with no dominant component, the lack of a Lyman limit break, and the multiple-component structure in NV suggest that this system does not represent a traditional disk/corona structure.

3. System B at $z = 0.9276$

The strong, blended MgII profiles could be fit with five narrow components, spread over $v \sim 200$ km/s in velocity space. The ionization parameters of the low-ionization phase clouds are $-3.2 \lesssim \log U \lesssim -2.5$ and the metallicity is constrained to be $\log Z \simeq -0.1$, by the partial Lyman limit break detected in the FOS spectrum. The dotted lines in Figure 1 represent the contribution from this phase.

The residuals in CIV, NV, and OVI indicate a highly ionized, diffuse phase. A broad component, with $b(\mathrm{N}) \sim 50$ km/s, is needed to fit the smooth NV absorption. An offset, narrower one, with $b(\mathrm{C}) \sim 14$ km/s, is also needed to account for the blue part of CIV. An ionization parameter of $\log U \simeq -1.6$ and a metallicity of $\log Z \simeq -0.6$ are required for both clouds for a photoionization model. The solid lines in Figure 1 show the two diffuse components. Collisional ionization is ruled out in this phase due to the observed ratio of CIII to CIV absorption.

An additional component, with $b(\mathrm{Si}) \sim 10$ km/s, is required to produce the observed SiIV absorption unaccounted for by either the MgII phase or the diffuse phase, in the cloud furthest to the red. This component could be photoionized or collisionally ionized. The collisional component, with a temperature $\log T \sim 4.8$, is represented by the dashed-dotted curves in Figure 1.

The MgII phase is likely to arise in the disk of a galaxy. The broad component in the diffuse phase may represent a corona structure similar to that of the Milky Way. Two candidate absorbing galaxies appear in a WIYN image of the quasar field at ~ 25 kpc and ~ 35 kpc.

4. System C at $z = 0.9342$

A weak, unresolved MgII cloud, aligned with the bulk of the CIV absorption in velocity space, is separated from System B, by $\sim 1,000$ km/s (see Figure 1). If the MgII cloud does not give rise to CIV, the ionization parameter of this phase is constrained to be $\log U \lesssim -3$ and the metallicity is $\log Z \simeq -0.6$. If, instead, the majority of CIV is produced by the MgII clouds, the ionization parameter is constrained to be $-2.2 \lesssim \log U \lesssim -2$ and the metallicity is close to the solar value.

Regardless of the ionization state of the MgII phase, the strong absorption in OVI (detected in the low-resolution HST/FOS spectrum) requires an additional, highly ionized component. If this component is photoionized, the ionization parameter would either be $\log U \simeq -1.5$ or $\log U \gtrsim -0.7$, depending upon whether CIV arises in the same phase or not. Alternatively, if the diffuse component is collisionally ionized, the temperature of this phase is constrained to be $\log T \gtrsim 5.4$. Figure 1 shows a model in which CIV is produced in the MgII phase and OVI (not shown) in a more highly photoionized phase. The dotted lines represent the model contributions from the MgII cloud, and the solid lines show those from the diffuse component.

In addition, a cloud offset ~ -40 km/s from the center of the MgII absorption is required by the Lya profile. This cloud also gives rise to the blue part of the CIV profiles. The dashed-dotted curves in Figure 1 represent this offset cloud.

The simple, weak absorption feature suggests that this system may be a high-velocity cloud or a dwarf galaxy. Two candidate associated galaxies are found in the WIYN image. They would be dwarfs and have impact parameters of 20–40 kpc, if at $z \sim 1$.

References

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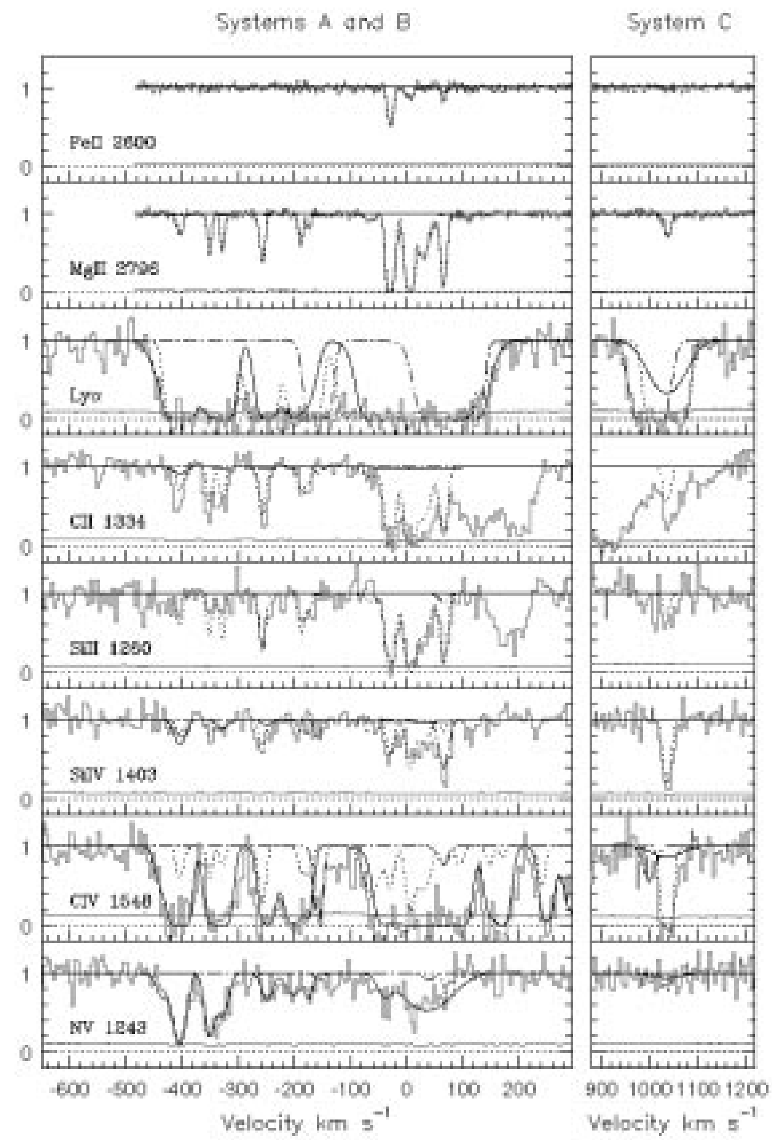

Figure 1. Various key transitions are displayed in velocity space, with the velocity zero-point at $z = 0.9276$. The solid histograms represent the normalized HST/STIS and Keck/HIRES data. The dotted lines show the contribution from the low-ionization phase in each system. The solid curves represent the photoionized, diffuse phase. The dashed-dotted lines show the intermediate phase.